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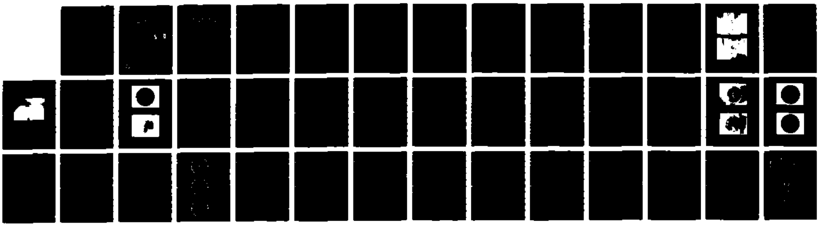

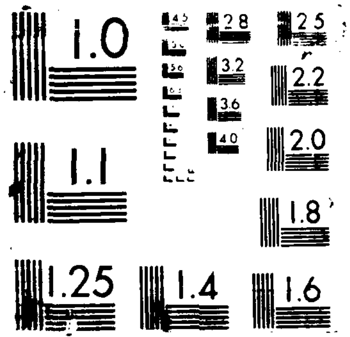
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A STUDY OF MOISTURE INTRUSION INTO THE TOW MISSILE LAUNCH TUBE

By

P. A. Cox

E. C. Schroeder

J. J. Labra, Ph.D., P.E.

FINAL REPORT
SwRI Project 15-7958-807

Prepared For

United States Navy
Pacific Missile Test Center (PMTC)
Pt. Mugu, California 93042

Performed as a Special Task for the Nondestructive Testing information Analysis Center under Contract No. DLA-900-84C-0910, CLIN 0001AG

May 5, 1985

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Thomas A. Cruse

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Twelve tests were conducted during this investigation to evaluate possible moisture intrusion into the TOW launch tube during high-speed flight in a rainfall. Simulated flight speed was 176 knots and rainfall rates were the equivalent of 2 in/hr. No free water was present in the tube after the tests and moisture intrusion was generally low. The maximum moisture gain was 1.4 grams in a 1 hr. test. This occurred once. All other tests gave moisture gains of 0.58 grams or less. Damage to the diaphragm on the front of the launch tube occurred in four tests. It was limited to separation of the backing material from the polyamide film. The damage may have affected the moisture gain in only one of the tests. Installation of the mushroom eliminated damage to the diaphragms in the four tests conducted. It did not affect moisture intrusion into the tube. Fourteen additional tests were conducted to study the effects of the diaphragm hole configuration, the airstream velocity and the angle between the launcher centerline and the airstream on moisture intrusion into the TOW missile launch

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tube. Without the mushroom installed, moisture intrusion was found to increase with an increase in hole size and to increase with a decrease in airstream velocity. With the mushroom installed, the effect of hole size and configuration was much less pronounced. Some reduction in moisture intrusion may be gained if holes are not placed at the bottom of the diaphragm.

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PREFACE

This project was performed by Southwest Research Institute for the U.S. Navy Pacific Missile Test Center (PMTC) as a special task under auspices of the Nondestructive Testing Information Analysis Center (NTIAC). Funding was provided through NTIAC under item No. 0001G of Contract DLA-900-84C-0910.

Task Manager was Dr. J.J. Labra of the Mechanical and Materials Sciences Division at Southwest Research Institute, and the technical monitor was Mr. Howard - Hatakeyama of PMTC. Coordination through NTIAC was provided by Dr. G.A. Matzkanin, Director of NTIAC.

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I. SUMMARY

Phase I

Twelve tests were conducted in this phase of the investigation to evaluate possible moisture intrusion into the TOW launch tube during high-speed flight in a rainfall. Simulated flight speed was 176 knots and rainfall rates were the equivalent of 2 in/hr. No free water was present in the tube after the tests and moisture intrusion was generally low. The maximum moisture gain was 1.4 grams in a 1 hr. test. This occurred once. All other tests gave moisture gains of 0.58 grams or less.

Damage to the diaphragm on the front of the launch tube occurred in four tests. It was limited to separation of the backing material from the polyamide film. The damage may have affected the moisture gain in only one of the tests. Installation of the mushroom eliminated damage to the diaphragms in the four tests conducted. It did not affect moisture intrusion into the tube.

Phase II

Fourteen tests were conducted in this phase to study the effects of the diaphragm hole configuration, the airstream velocity and the angle between the launcher centerline and the airstream on moisture intrusion into the TOW missile launch tube. Without the mushroom installed, moisture intrusion was found to increase with an increase in hole size and to increase with a decrease in airstream velocity. With the mushroom installed, the effect of hole size and configuration was much less pronounced. Some reduction in moisture intrusion may be gained if holes are not placed at the bottom of the diaphragm.

II. INTRODUCTION

Historical data gathered by the Navy concerning the TOW missile in a captive carry mode have suggested potential missile launch problems associated with moisture intrusion. In particular, in a captive flight, moisture and/or free water may enter the TOW launch tube. This, in turn, could damage critical components of the missile.

The objectives of the study performed were to:

(1) determine whether or not free water is accumulated in the TOW launch tube during highspeed captive carry flight;

(2) measure the rate at which moisture and/or free water enters the launch tube.

(3) Evaluate alternative diaphragm configurations.

Two series of laboratory tests were performed to satisfy the objectives. In Phase I, test conditions simulated 200 mph airspeed and direct rain impingement on the front of the launch tube. The airstream was parallel to the axis of the launch tube, and the rain impingement rate would equate to rainfall rates of about 2 in/hr. Tests without rain impingement and airflow were performed to study moisture intrusion under static or non-flight conditions. In Phase II, the test series included airstream velocities of 90 mph and 175 mph, inclination of the launch tube with respect to the airstream and modified diaphragms on the front of the TOW launch tube. In both phases tests were performed with and without the mushroom installed in the front extension of the launch tube.

III. TEST APPARATUS

To simulate rain impingement on the launcher during flight, a metered amount of water was continuously injected into a high velocity airstream which was directed at the front of the TOW launch tube. The high velocity airstream was obtained with a large centrifugal blower. A transition section was attached to the blower to produce a 10-inch diameter circular stream for impingement on the launch tube.

Overviews of the test setup are shown in Figure 1. The TOW launch tube, with an aluminum front extension and with the mushroom installed, is shown in place, in front of the blower outlet. The tube also could be mounted at 45, to the airstream with the opening of the front extension still in the center of the airstream. Spacing between the blower outlet and the mushroom was approximately 8 inches for all tests. A long extension pipe was placed on the inlet to the blower and airspeed was controlled by an adjustable flapper value on the pipe inlet. Airspeed was monitored with a pitot tube at the blower outlet, and the dynamic pressure was measured with a water manometer.

Water was injected into the airstream just ahead of the transition piece. For airstream velocities of 200 mph (Phase I), injection was through the four static ports of a pitot tube. At lower airspeeds (Phase II), a small spray nozzle, which injected water more in line with the airstream, was used. An adjustable-speed metering pump produced a constant flow of deonized water to the pitot tube. Flow rates were calibrated by static flow tests into graduated beakers. Actual water usage was measured during the tests.

Moisture intrusion into the launch tube was monitored by the use of dessicate paper placed at each end of the tube. For most of the tests in Phase I and all tests in Phase II a center seal was used to effectively isolate the front half from the rear half of the tube. This was done to

FIGURE 1. TEST APPARATUS AND TOW LAUNCH TUBE

isolate the front half from the rear half of the tube. This was done to obtain baseline or background moisture readings at the rear of the tube for comparison with measurements at the front of the launcher where the water impingement occurred. Weights of the dessicate paper were obtained immediately before and after each test. The dessicate was sealed in plastic bags for transit to and from the scales. Some moisture absorption outside of the tube was unavoidable, but since relative readings were sought, this absorption was compensated for. At the end of each test the front of the tube was examined for free water.

Two basic configurations of the launch tube were tested, one with and one without the mushroom in the launch tube support extension. The installed mushroom is visible in Figure 1, already presented. Without the mushroom the front face of the diaphragm can be seen as shown in Figure 2. In addition, the support extension was mounted in two different ways from the case extension ring. In the first five tests of Phase I the support extension was placed tightly against the case extension ring. Beginning with Test 6 in Phase I and for all subsequent tests a 0.120 in. gap was left between the support extension and the case extension ring. As will be discussed under the test results, less water accumulated in front of the diaphragm when the gap was present.

FIGURE 2. FRONT OF DIAPHRAGM AS SEEN LOOKING THROUGH THE FRONT OF THE SUPPORT EXTENSION

IV. TEST PROCEDURE

The test procedure evolved as the testing progressed. For example, dessicate paper was only placed at the front of the launch tube for Test No. 1 and a center seal was added after Test No. 5; however, the general procedure was quite similar for all tests and was as follows:

(1) Fill beaker with a measured quantity of deconized water and check water lines;

(2) Check pitot tube alignment and connections to the manometer;

(3) Set flapper value at blower inlet to one inch maximum opening for blower startup;

(4) Weight front and rear dessicate packets (Figure 3a) and seal in plastic bags;

(5) Place dessicate paper in the launch tube and install front and rear diaphragms (Figure 3b). Secure diaphrams in place with mormon clamps. Note! The launch tube support extension was supported from the case extension ring.

(6) Take ambient barometric pressure, temperature and relative humidity readings;

(7) Turn on blower and adjust flapper value until the manometer reads 19 inches;

(8) Start metering pump and timer;

(9) Replenish water beaker with measured amounts of deconized water as required;

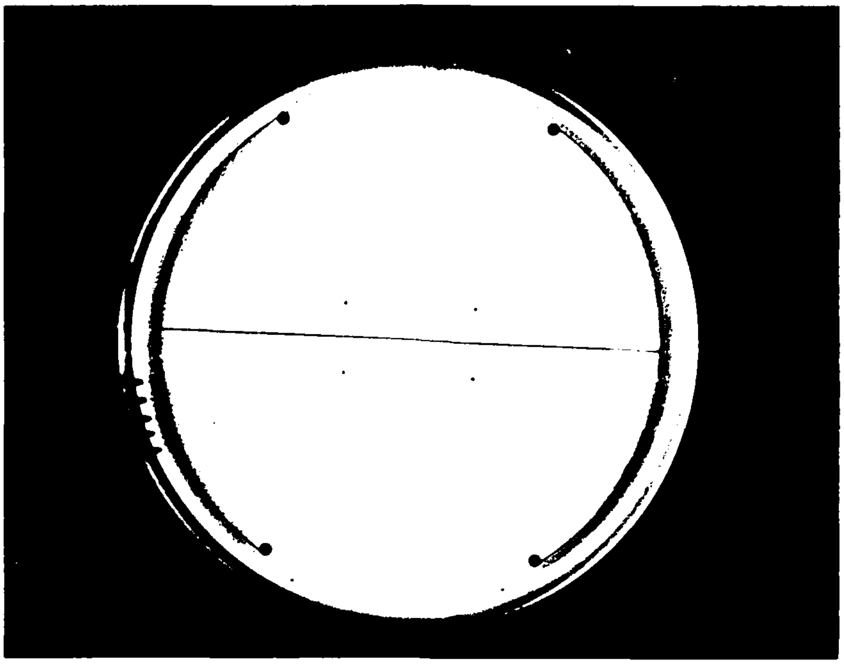
(10) At end of test (usually 20, 40 or 60 minutes) stop metering pump and then the blower;

(11) Remove front case extension ring and examine tube for free water;

(12) Remove dessicate packets from the front and rear of the tube and weigh immediately.

(13) Record water usage, final temperature and relative humidity.

This procedure was followed for all tests without the mushroom. In Phase I, when the mushroom was installed in the front of the launch tube support extension, it was weighed in Step (4), installed in Step (5), and removed and



(b) Diaphragm No. 5 - Back Side

(a) Dessicate Paper Packet

FIGURE 3. EXAMPLES OF AN UNDAMAGED DIAPHRAGM AND THE DESSICATE PAPER USED IN THE TESTS

weighed in Step (11). The mushroom was not weighed in Phase II testing. One other difference occurred between Phases I and II. All Phase II tests were performed with newly reactivated dessicate. The dessicate was reactivated by baking it for 5-10 minutes at 300°F. In Phase I the dessicate material was used for several tests before it was reactivated.

V. PHASE I TESTING

A. Test Matrix

A matrix of the tests performed is given in Table I. All but three of the tests were performed with water impingement. The tests without water impingement, the static tests, were performed to measure the ambient or background moisture in the tube. By comparison with the dynamic tests, they help to establish the amount of moisture in the tube produced by the water impingement. Tests 13 and 14, with the mushroom installed, are repeats of Tests 10 and 11. Problems with the dessicate on Tests 10 and 11 gave invalid results and they were discarded.

B. Test Results

Results are divided into those for the static and those for the dynamic tests. Static tests results are presented first because they provide a basis for determining the "background" moisture which would be absorbed by the dessicate without water impingement. This amount is subtracted from the total moisture absorbed (usually by the front dessicate) to determine the moisture intrusion caused by rainfail during high-speed flight.

1. Static Tests

Static test results are summarized in Table II. Tests 5 and 6 were conducted in the laboratory where the dynamic tests were performed. In the laboratory the launch tube is shaded from the sun and, with the laboratory doors closed, temperatures stabilize at about 77°F. Test 8 was conducted outside on a rooftop and the launch tube was subjected to direct sunlight and high noon time temperature (100°F). At night, temperatures dropped to about 73 F.

The moisture absorption results for Test 8 are not valid because the saturation capacity of the dessicate paper was exceeded at the high

TABLE I

TEST MATRIX FOR PHASE I

TEST NO.	DIAPHRAGM NO.	TEST TIME	WATER SPRAY	CENTER SEAL	DESSICATE *	MUSHROOM
1	1	20 min.	YES	NO	YES	NO
2	2	20 min.	YES	NO	YES	NO
3	2	20 min.	YES	NO	YES	NO
4	2	60 min.	YES	NO	YES	NO
5	2	2 hr.	NO	NO	YES	NO
6	3	2 hr.	NO	YES	YES	NO
7	3	60 min.	YES	YES	YES	NO
8	4	48 hr.	NO	NO	YES	NO
9	4	60 min.	YES	YES	YES	NO
10	5	60 min.	YES	YES	YES	YES
11	5	60 min.	YES	YES	YES	YES
12	6	60 min.	YES	YES	NO	NO
13	7	60 min.	YES	YES	YES	YES
14	8	60 min.	YES	YES	YES	YES

*Except for Test No. 1 (and No. 12 which had no dessicate) dessicate paper was placed in the front and rear of the launch tube.

TABLE II

SUMMARY OF PHASE I STATIC MOISTURE INTRUSION TESTS

TEST NO.	TEST TIME	DIAPHRAGM NO.	MEASURED MOISTURE GAIN		CALCULATED AMBIENT MOISTURE		MEAS/CALC		COMMENTS
			FRONT (gm)	REAR (gm)	FRONT (gm)	REAR (gm)	FRONT	REAR	
5	120 min.	2	.1314	.1643	.2152	.2152	.611	.7634	NO CENTER SEAL; DIAPHRAGM BACKING SEPARATED BEFORE THIS TEST
6	20 min.	3	.1942	.2680	.1700	.1700	1.142	1.576	NEW DIAPHRAGM; CENTER SEAL
	40 min.	3	.1579	.1719	.1473	.1473	1.072	1.167	
	60 min.	3	.1545	.1362	.1440	.1440	1.073	.946	
8	48 hr.	4	-.6167	.1966	.2262	.2262	-2.726	.869	NEW DIAPHRAGM; NO CENTER SEAL

temperatures and moisture was actually "baked" out of the dessicate. This is shown in Table III which gives an evaluation of the dessicate capacity to absorb moisture in all Phase I tests. Table III gives the dessicate weight at the start and conclusion of each test and the allowable weight (saturation weight) of the dessicate at the test temperature and relative humidity. The allowable weight was estimated from data provided by the dessicate manufacturer, Multiform Dessicates, Inc. Only for Tests 8 and 10 were the saturation weight⁻ of the dessicate exceeded and the dessicates actually lost moisture during the tests. It is not surprising that the temperatures were high enough in Test No. 8, during the exposure of the tube on the roof. to "bake" moisture from the dessicate. It is surprising that the dessicate lost moisture during Test No. 10.

The significant result from the static tests is that the dessicate appears to absorb the ambient moisture in the tube within the first 20 minutes and then not absorb much more. Test 6 shows that absorption was less for the longer duration than for the shorter duration parts of the test, even though Table III shows that the dessicate was not close to saturation. Two factors may have caused this result. Some moisture may have been present in the fiberglass lining of the tube which was drawn out during the 20 min. and 40 min. parts of Test 6. Also, although the tube was opened between the 20, 40 and 60 minute parts of Test 6, ambient laboratory air may not have fully diffused into the tube. These same factors could have caused the low ratio of measured to calculated moisture observed in Test 5 also.

To measure moisture intrusion in the launch tube caused by water impingement, the "background" moisture, such as measured in the static tests, was subtracted from the moisture measured in the dynamic tests. To be conservative, the smaller of the calculated or measured value of background moisture was used for the adjustment.

TABLE III.

EVALUATION OF DESSICATE CAPACITY
PHASE I TESTING

TEST NO.	DESS. NO.	FT. DESS. WT (gm)	REAR DESS. WT (gm)	TEMP. (°F)	R.H. (%)	SATURATION WT (gm)
No. 2 START STOP	1	30.2285 30.7737	30.1162 30.2843	80_e*	70_e	33.77
No. 3 START STOP	1	30.7737 30.9905	30.2843 30.3669	80_e	70_e	33.77
No. 4 START STOP	1	31.0566 31.9872	30.4281 31.3785	78	78	34.56
No. 5 START STOP	1	31.9872 32.1186	31.3785 31.5428	82.5	72	33.48
No. 6 START STOP	2	30.8775 31.0717	30.2344 30.5024	78	75	34.38
START STOP	2	31.0717 31.2296	30.5024 30.6743	77	67	34.06
START STOP	2	31.2296 31.3841	30.6743 30.8105	77	65.5	33.92
No. 7 START STOP	2	31.5107 32.1920	30.9858 31.1966	82	79	33.94
No. 8 START STOP	2	32.2061 31.5894	31.2270 31.4236	92	57	31.23
No. 9c START STOP	2	32.9315 33.4675	32.1043 32.2185	83	77	33.67
No. 10 START STOP	2	33.4634 33.1044	32.2337 32.1587	80	65	33.42
No. 11 START STOP	2	33.2316 33.2852	32.2359 32.3576	80	85	34.63
No. 13 START STOP	1**	28.0464 28.6950	27.9165 28.3953	76	66.5	34.18
No. 14 START STOP	2**	28.3625 28.9728	28.2920 28.7781	79	73	34.10

*80_e indicates that the value (80) was estimated.

**Reactivated Dessicate.

2. Dynamic Tests

Results for the dynamic tests are summarized in Table IV. All tests were conducted with a center airstream velocity of 203-205 mph. The average stream velocity was less, but the launch tube was centered on the blower outlet and so was exposed to the maximum air velocity.

The equivalent rainfall was computed based upon the blower outlet diameter of 10 inches and a uniform distribution of moisture over the duct opening. It was apparent that higher moisture was present in the center of the duct, and since the opening of the launch tube support extension was only 6 inches, a higher equivalent rainfall than calculated probably impinged on the front of the launcher. To calculate the equivalent rainfall, it was necessary to know the velocity at which rain falls. A velocity of 120 mph was assumed.

During the tests some pooling of water occurred in the tube support extension and the accumulated water was thrown in droplets against the diaphragm. More water accumulated in the support extension for Tests 1-5 than for subsequent tests, but the pooling still occurred in all tests. As noted in the description of the Test Apparatus, a gap was added between the tube support extension and the case extension after Test No. 5. The two parts were butted together for Tests 1-5.

Front and rear moisture gain was measured in all tests but Test No. 1; however, in Tests 2 through 5, no center seal was used to isolate the front and rear dessicates. For these tests, the "background" moisture was calculated from the ambient moisture and temperature at the time the tube was closed (diaphragm installed). This background moisture was subtracted from the total moisture gained during the tests to determine the moisture gain associated with rain impingement. Overall, the results for all dynamic tests are quite similar. Only two tests stand out from the rest, Test Nos. 3 and 4.

TABLE IV.

SUMMARY OF PHASE I DYNAMIC MOISTURE INTRUSION TESTS

TEST NO.	DIAPHRAGM NO.	V (mph)	R.F. (in/hr)	TEST TIME (min)	MOISTURE GAIN FRONT (gm)	MOISTURE GAIN REAR (gm)	BACKGROUND MOISTURE (gm)	EST. NET GAIN THROUGH FT. DIA. (gm)	VISUAL POST TEST CONDITION OF DIAPHRAGM	COMMENTS
1	1	204	3.4	20	.9945	No dess.	.4188	.576	BACKING SEPARATED (Figure 4a)	NO CENTER SEAL NO MUSHROOM
2	2	205	1.8	20	.5452	.1681	.4555	.258	UNDAMAGED	"
3	2	205	1.8	20	.2168	.0826	.4555	-.1561	UNDAMAGED	"
4	2	204	1.8	60	.9306	.9504	.4801	1.401	BACKING SEPARATED (Figure 4b)	"
7	3	205	2.3	60	.6817	.2108	.2026	.479	UNDAMAGED	CENTER SEAL NO MUSHROOM
9C	4	205	2.0	60	.5380	.1142	.1142	.4238	SLIGHT BACKING SEPARATION (Figure 4c)	"
12	6	204	2.1	60	-	-	-	-	-	NO FREE WATER IN TUBE AFTER THE TEST
13	7	203	1.9	60	.6486	.4788	.1629	.4857	UNDAMAGED	CENTER SEAL MUSHROOM*
14	8	204	2.0	60	.6103	.4861	.1953	.4150	UNDAMAGED	"

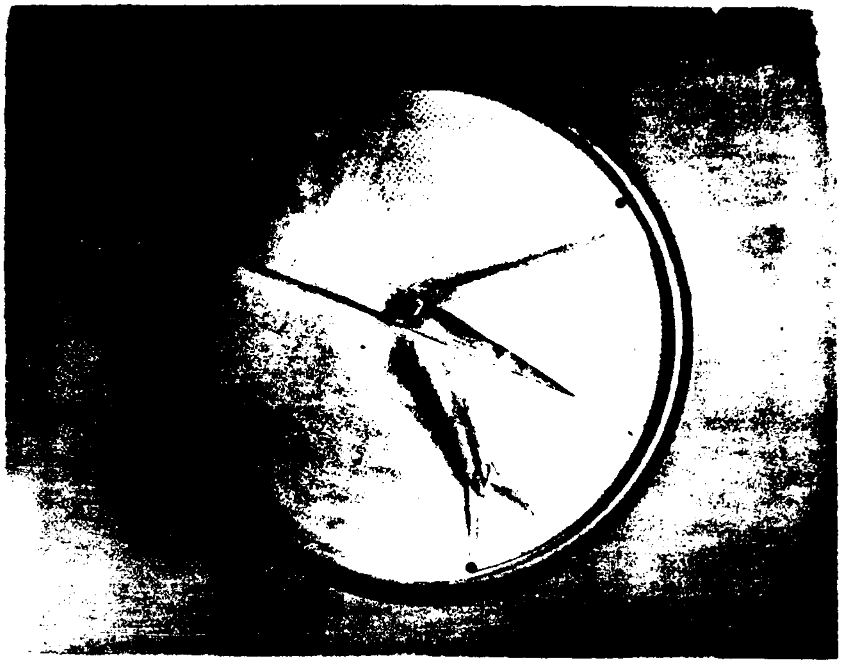
*The mushroom gained 8.84 gms. of water in Test No. 13 and 6.85 gms. of water in Test No. 14. Some water accumulated in the support extension behind the mushroom during the tests.

In Test No. 3 the tube apparently lost moisture during the test and in Test No. 4 the tube gained much more moisture than expected. A check of Table III shows that the dessicates were well below saturation limits. Further, the dessicate weights appear to be consistent between the two tests. The result for Test No. 3 is similar to Test No. 5, a static test, in which the dessicate absorption was less than the calculated background moisture. We discussed possible reasons for this under the static test results. The addition of a negative tare to the scales after the initial weighing for Test No. 3 and removal of the tare before the final weighing for Test No. 4 could have produced the results obtained. We believe that this is unlikely, and treat Tests No. 3 and 4 as normal variations in the test data.

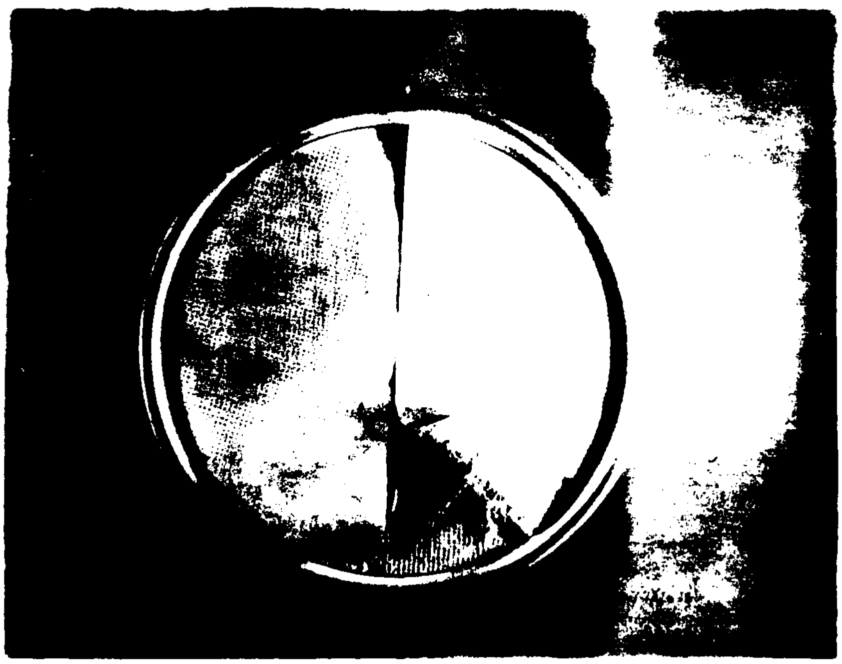
Damage occurred to the diaphragms in Tests No. 1, 4 and 9C. The damage was limited to a separation of the backing from the polyamide film as shown in Figure 4. Only Test No. 4 (Diaphragm No. 2) shows an increase in moisture intrusion which could be associated with the damage. Diaphragm No. 2 was exposed to the airstream for 120 minutes. Only Diaphragm No. 4 was exposed longer. Three repeat tests were run with diaphragm No. 4, Tests No. 9A, 9B and 9C, which subjected it to 180 minutes in the airstream. These tests were repeated because the center seal collapsed during Tests No. 9A and 9B.

C. Conclusions From the Phase I Testing

Overall, the moisture intrusion was low and no free water accumulated in the tube during the tests. It appears that a reasonable upper limit for moisture intrusion is 1.4 grams in one hour for the conditions tested. Normally, the moisture gain should be 0.5 grams or less in a one hour test. These test results should not be extrapolated to longer times or different airstream velocities without additional testing.

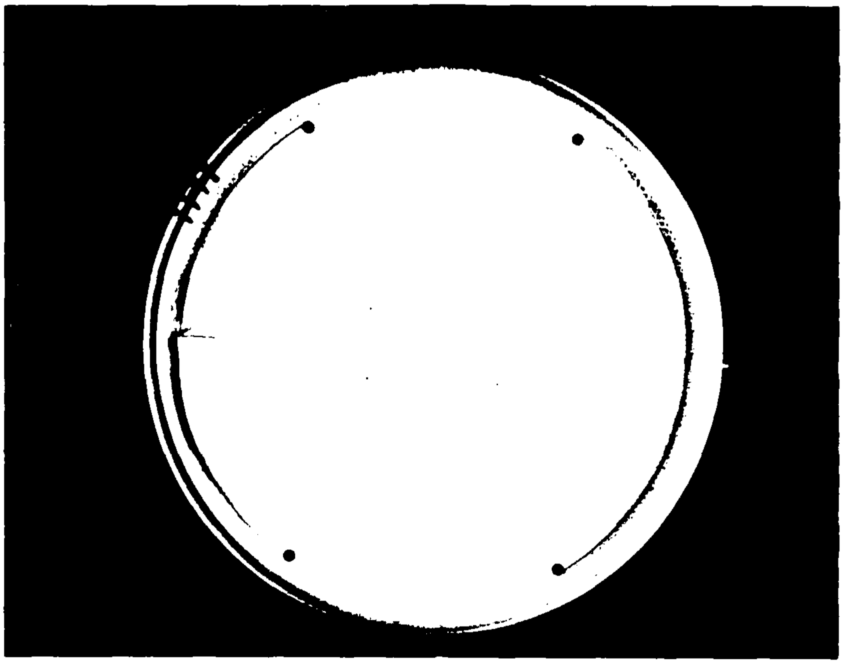


(a) Diaphragm No. 1

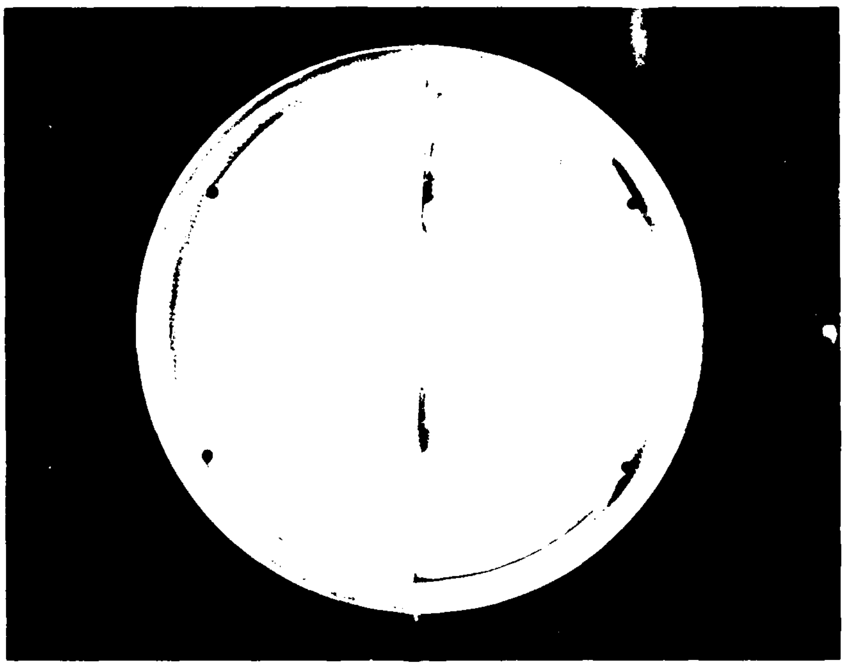


(b) Diaphragm No. 2

FIGURE 4. BACKSIDE OF DAMAGED DIAPHRAGMS (Cont'd.)



(c) Diaphragm No. 4



(d) Diaphragm No. 6

FIGURE 4. BACKSIDE OF DAMAGED DIAPHRAGMS (Concluded)

Without the mushroom installed, some damage to the diaphragms can be expected during high-speed flight in rainfall; however, damage is limited to separation of the backing material from the polyamide film. The effect of diaphragm damage on moisture intrusion was mixed in the test results obtained in this phase of the investigation. With the mushroom installed, damage to the diaphragms was avoided but moisture intrusion was unaffected.

VI. PHASE II TESTING

A. Test Matrix

In Phase II of the testing, additional tests were performed to show how moisture intrusion is affected by reducing the flight speed and by changing the angle of air impingement on the launch tube. The effects produced by design changes to the diaphragm were also investigated. A matrix of the tests conducted in this phase is given in Table V. A new numbering system, restarting with "1", was used for test and diaphragm numbers in Phase II.

The "Std" under the diaphragm configuration refers to the standard hole configuration in the diaphragm shown in Figure 5(a). When 0.040-inch holes are specified with the standard diaphragm, the holes in the diaphragm were enlarged with a 0.040-inch diameter drill. The 0.040-inch drill was also used to produce the holes in the MOD 1 diaphragms so that the holes were of maximum size. A 0.028-inch diameter drill was used to create holes in the MOD 2 diaphragms.

Hole dimensions were measured with a calibrated microscope after the testing. A few were measured both before and after with no apparent change in the dimensions. Hole dimensions and the total hole area in each diaphragm are given in Table VI. Some of the holes, particularly the as-received holes, were irregular in shape and often had a lip which protruded forward from the face of the diaphragm. Thus, the holes were treated as ellipses and both major and minor axes were measured. The formula for an ellipse was used to calculate the areas. Only diaphragm 3B and the MOD 2 diaphragms were treated differently. Diaphragm 3b had intersecting holes in two places, a smaller hole intersecting the 0.040-inch diameter hole. Appropriate formulas were used to calculate the area for diaphragm 3B. In addition, one of the other

TABLE V

TEST MATRIX FOR PHASE II*

Test No. and Diaphragm No.	Diaphragm Config.	Airstream Velocity	Airstream/ Launch Tube	Front Extension	Mushroom
1	Std	175 mph	0°	no	no
1A	Std 0.040" Holes	175 mph	0°	yes	no
1B	Std 0.040" Holes	175 mph	0°	yes	no
2	Std	175 mph	45°	no	no
2A	Std 0.040" Holes	175 mph	45°	yes	no
3	Std	90 mph	0°	no	no
3A	Std 0.040" Holes	90 mph	0°	yes	no
3B	Std 0.040" Holes	90 mph	0°	yes	no
4	Std 0.040" Holes	175 mph	0°	yes	yes
5	MOD 1 Hole at Bottom	175 mph	0°	yes	yes
6	MOD 1 Hole at 45°	175 mph	0°	yes	yes
7	MOD 2 Hole at Bottom	175 mph	0°	yes	yes
8	MOD 2 Hole at 45°	175 mph	0°	yes	yes
9	Std/Holes Sealed	175 mph	0°	yes	yes

*All tests conducted with a center seal, dessicate material in both ends and water spray.

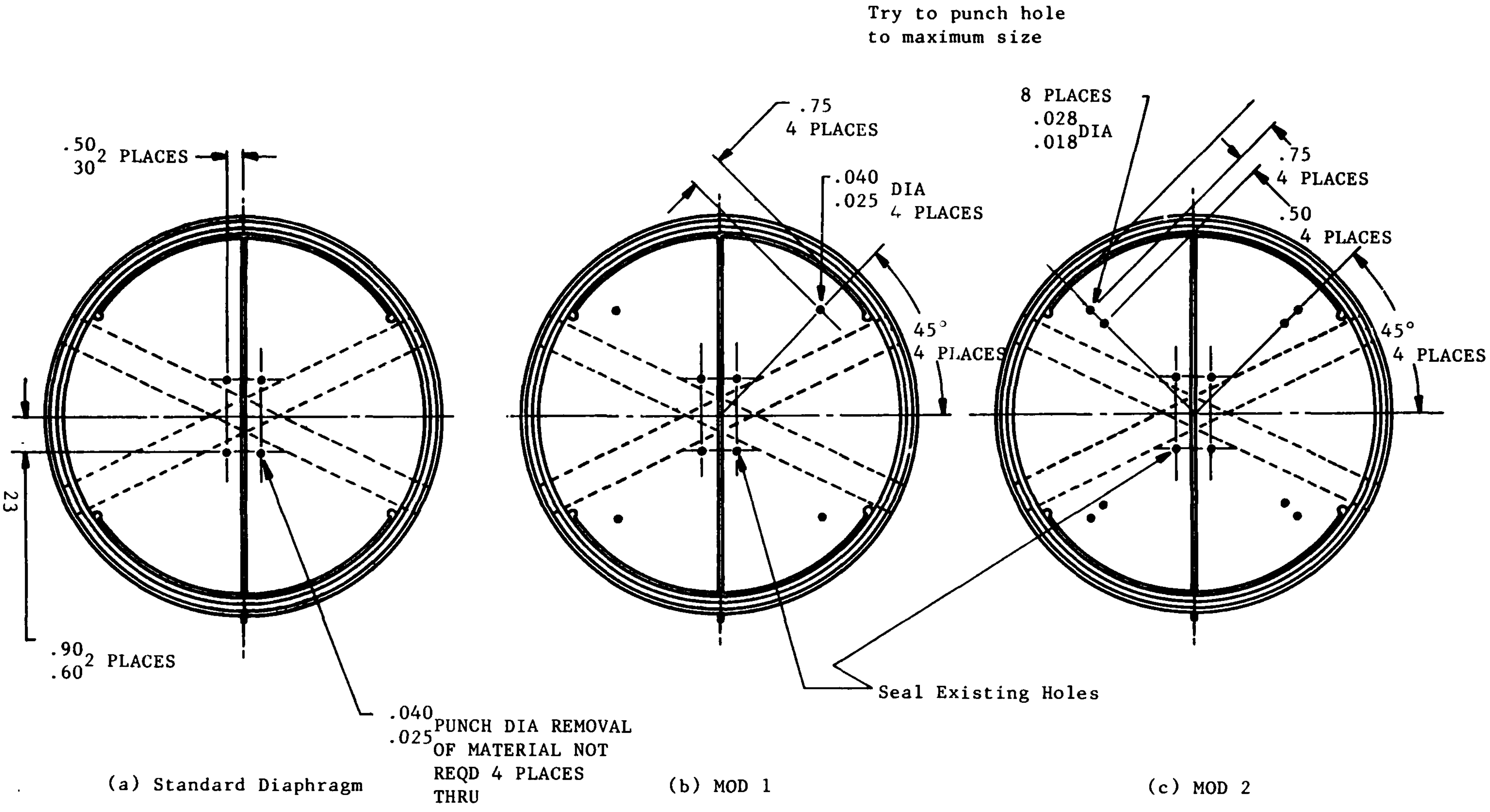


FIGURE 5. DIAPHRAGM CONFIGURATIONS

TABLE VI

DIAPHRAGM HOLE DATA

Diaphragm No.	Hole Dimensions (in.) : Majcr and Minor Axes								Total Area (in^2)
	A	B	A	B	A	B	A	B	
1	.025	.025	.028	.028	.028	.028	.028	.028	.002338
1A	.04	.04	.04	.04	.043	.04	.04	.038	.005058
1B	.041	.036	.04	.04	.04	.04	.04	.039	.004898
2	.025	.025	.027	.027	.028	.028	.021	.02	.002009
2A	.045	.039	.038	.038	.04	.04	.04	.038	.004963
3	.03	.03	.02	.02	.028	.028	.02	.02	.001951
3A	.04	.04	.04	.04	.04	.04	.04	.04	.005027
3B	.04	.04	.04	.04	.04	.025	.04	.01	.005311
4	.04	.04	.04	.04	.04	.04	.04	.04	.005027
5	.04	.04	.04	.04	.04	.04	.04	.04	.005027
6	.04	.04	.04	.04	.04	.04	.04	.04	.005027
7	.028	.028	.028	.028	.028	.028	.028	.028	.004926
8	.028	.028	.028	.028	.028	.028	.028	.028	.004926
9	0	0	0	0	0	0	0	0	0

0.040-inch diameter holes in diaphragm 3B had two radial tears on one side which were about 0.01-inches long and 0.01-inches apart. The edge of the hole protruded forward between the tears. The tears were neglected in the area calculations. The MOD 2 diaphragms had eight 0.028-inch diameter holes so each entry represents a separate hole. The influence of hole area and hole geometry on moisture intrusion through the diaphrams is discussed in the results section.

B. <u>Test Results</u>

Results of the Phase II testing are summarized in Table VII. As noted previously, the main objectives of the tests in this phase were to evaluate different diaphragm configurations and the effects of airstream velocity and direction. Four basic diaphragm configurations were tested: (1) the as-received, "std." configuration, (2) the standard diaphragm with all holes enlarged to 0.040 inches, the maximum hole diameter specified for the diaphrams, (3) a MOD 1 diaphragm (Figure 5b) and (4) a MOD 2 diaphragm (Figure 5c). As Figure 5 shows, the MOD 2 diaphragm was like the MOD 1 diaphragm except that each 0.040-inch hole was replaced with two 0.028-inch holes. In addition to the diaphragm configurations, two different wind directions, 0, and 45,, and two different airstream velocities, 173 and 89 mph, were tested. All tests were conducted with an equivalent rainfall of about 2 in/hr, and test durations were 1 hr. The mushroom was omitted in Tests 1 through 3b and installed in Tests 4 through 9.

Only three diaphragms were tested in the as-received condition. These are the "std." diaphragms noted for tests 1, 2 and 3. They show a much smaller moisture intrusion than for the other tests without the mushroom. The trend follows the hole area but does not correlete well with it. For example, the results of Tests 1 and 1a correlate well with hole size, but the results

TABLE VII

SUMMARY OF PHASE II DYNAMIC MOISTURE INTRUSION TESTS

Test No. & Diaph. No.	Diaphragm Configuration	Total Hole Area (in^2)	Airstream Angle (Degrees)	Velocity (MPH)	Rain Fall (IN/HR)	Front Extension*	Moisture Gain** Front (GM)	Moisture Gain** Rear (GM)	Background Moisture (GM)	Moisture Gain, Front Diaphragm (GM)
1	STD.	.002338	0	173.6273	2.0156	no	.5073	.2732	.2732	.2341
1A	STD/.040" Holes	.005058	0	173.3059	2.0194	yes	.7493	.3020	.3020	.4473
1B	STD/.040" Holes	.004898	0	173.2998	2.0140	yes	.9088	.2007	.2007	.7081
2	STD.	.002009	45	173.3182	2.0192	no	.3466	.2441	.2441	.1025
2A	STD/.040" Holes	.004963	45	173.4636	2.0068	yes	1.5484	.2603	.2603	1.2881
3	STD.	.001951	0	89.3425	2.0185	no	.4038	.2273	.2273	.1765
3A	STD/.040" Holes	.005027	0	89.3831	2.0228	yes	2.5578	.2969	.2969	2.2609
3B	STD/.040" Holes	.005311	0	89.1442	2.0126	yes	3.7637***	.3128	.3128	3.4509
4	STD/.040" Holes	.005027	0	173.6212	2.0157	yes	.4664	.2896	.2896	.1768
5	MOD 1 Hole at Bottom	.005027	0	173.0083	2.0228	yes	.4118	.2481	.2481	.1637
6	MOD 1 Hole at 45°	.005027	0	173.3182	2.0300	yes	.3320	.2369	.2369	.0951
7	MOD 2 Hole at Bottom	.004926	0	173.7803	2.0246	yes	.6006	.3805	.3805	.2201
8	MOD 2 Hole at 45°	.004926	0	173.7803	2.0138	yes	.5348	.3725	.3725	.1623
9	STD. Holes Sealed	0	0	174.1046	2.0101	yes	.1410	.1330	.1330	.0080

*The mushroom was installed for tests 4-9 only
**All tests were 1 hr. in duration
***Free moisture observed behind the front diaphragm in this test only

of Tests 2 and 2a do not. Results of these tests may be somewhat biased by the fact that there was no front extension on the launch tube for Tests 1, 2 and 3.

The effect of the airstream direction is shown by comparing the results of Tests 1, 1a and 1b with Tests 2 and 2a. With the standard diaphragm the moisture intrusion was reduced when the airstream angle was increased. With the 0.040-inch holes the opposite effect is observed. It appears that we are operating in a regime in which moisture intrusion is very sensitive to hole size and airstream velocity. The most important effect of the airstream angle may be to reduce the apparent airstream velocity. If this is the case, the results for the 45° airstream angle should be evaluated in light of the results for lower airstream velocity.

Tests 3, 3a and 3b were conducted with an airstream velocity of 89 mph as compared to 173 mph for all other tests. For the standard diaphragm, there is no apparent effect of the reduced velocity relative to Tests 1 and 2; however, for the larger holes, the results are quite different. Reduced velocity produces higher moisture intrusion for the larger holes. For these comparisons, a 45° angle produces a normal velocity of 122 mph in Tests 2 and 2a. A small increase in hole size also appears to have a significant influence on the moisture intrusion. For Test 3b the total hole area was slightly larger than for Test 3a, yet much higher moisture intrusion occurred. Not only was higher moisture absorbed by the dessicate, but free moisture was found in the front of the launch tube at the conclusion of the test. Test 3b was the only test, out of all tests conducted in Phases I and II, in which free moisture was observed in the tube at the conclusion of a test.

It is difficult to explain the causes of the observed differences in moisture intrusion because of the complicated flow field in front of the diaphragm. We offer one plausible, but not proven, explanation for the observed effects. The flow along the surface of the diaphragm must be parallel to the diaphragm surface. Simulated flow fields, over four different hole configurations, are shown in Figure 6. Configurations (a) and (b) represent some of the holes in the as-received diaphragms. Some holes are small and some have lips that protrude to the front of the diaphragm. For a given pressure differential, ΔP, across the hole, these configurations will have less flow through the hole than for configurations (c) and (d). The larger the hole, the more time (at a constant velocity) for the flow to turn and enter the hole. Clearly, configuration (d) acts as a scoop and configuration (b) acts to divert the flow from the hole.

The pressure differential and airstream velocity clearly influence the flow through the hole. Higher incident velocity will give higher flow velocity along the diaphragm surface, and higher velocity parallel to the surface will reduce flow through the hole; however, higher incident velocities may also increase the pressure differential across the hole which will increase flow through the hole. Additional calculations, beyond the scope of this study, are necessary to quantify the causes for the observed behavior.

With the mushroom in place, Tests 4-9, moisture intrusion is reduced substantially and none of the factors discussed above should have much bearing on the results. The results show a slight advantage for holes placed at the 45° angle. Of course, sealing the holes completely, as in Test 9, very significantly reduced moisture intrusion. Test 9 gives some indication of the amount of moisture which diffuses through the polyamide film itself without holes.

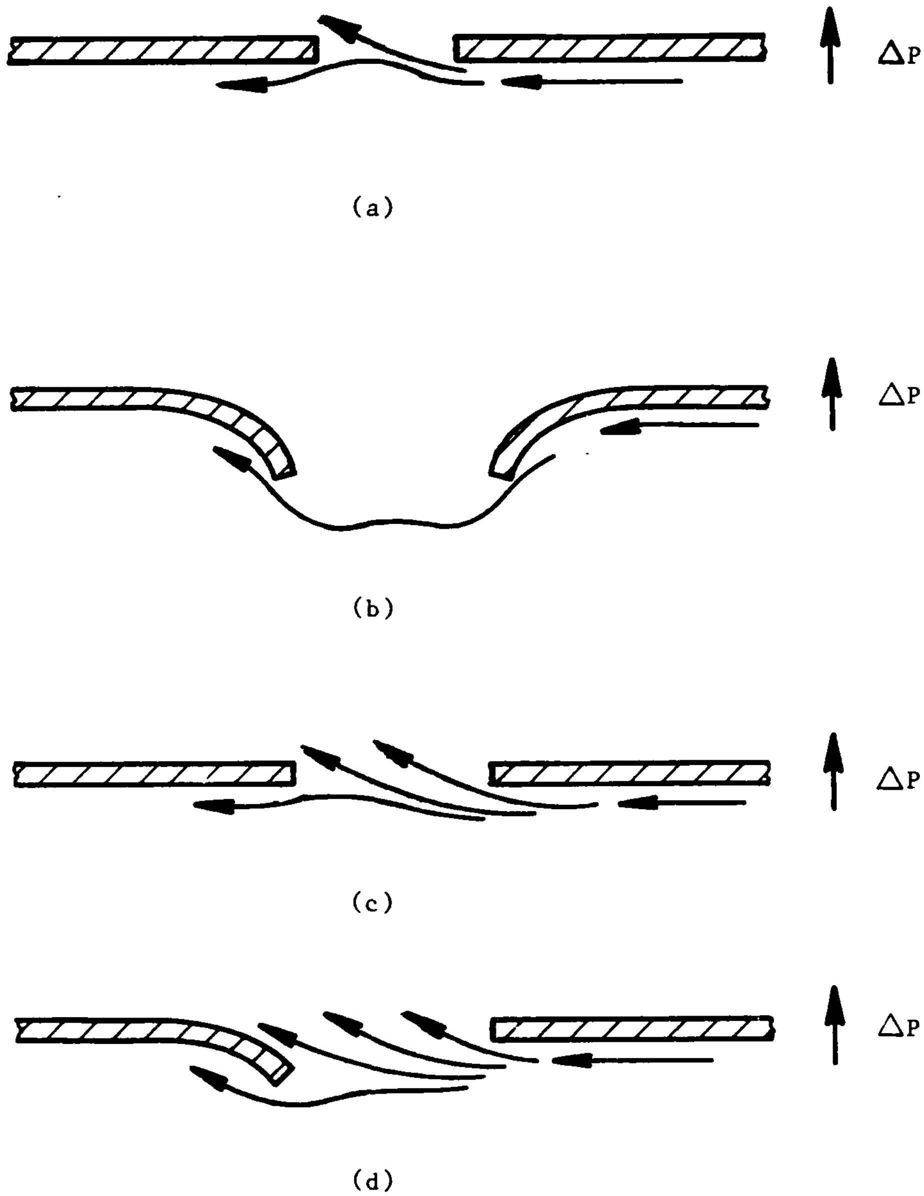


FIGURE 6. FLOW ABOUT TYPICAL HOLE CONFIGURATIONS

C. Conclusions From the Phase II Testing

Phase II testing has shown that, without the mushroom in place, high velocities do not produce the highest moisture intrusion. In fact, for hole sizes of 0.040 inches in diameter, the reverse is true. The effect of wind angle is slight, except for the effect that it has on reducing the apparent wind speed normal to the diaphragm surface. With the mushroom in place the diaphragm configuration is not very important, but there is some evidence that a hole placement at 45, to the vertical, rather than at the bottom, gives a reduction in moisture intrusion. It should also be noted that the moisture intrusion which occurred for the modified diaphragms in tests with the mushroom installed, was not substantially different from that which occurred in tests without the mushroom for the as-received diaphragm. This supports a conclusion reached in the Phase I testing, i.e., that the mushroom did not effect moisture intrusion. This conclusion is not valid for larger holes in the diaphragms as tested in Phase II.

VII. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

The following conclusions can be drawn from the investigations documented in this report:

1. With the mushroom installed, the hole configuration of the diaphragm does not significantly affect the moisture intrusion into the TOW launcher and no free moisture should enter through the diaphragm.

2. Without the mushroom, moisture intrusion is strongly affected by the hole size and wind speed. Low wind velocities and large holes (0.040 inches in diameter) produce the highest moisture intrusion.

3. The influence of the wind angle, with respect to the axis of the launcher, is to reduce the wind velocity normal to the diaphragm. For the large holes, moisture intrusion increased with wind angle. For the as-received diaphragm, with smaller holes, moisture intrusion decreased slightly.

4. A sharp reduction in moisture intrusion occurs when the holes are completely sealed.

5. Free moisture will rarely enter the launcher through the diaphragm. Further, it should never occur with the mushroom in place. It is most likely to occur with no mushroom, holes larger than 0.040 inches in diameter and at low wind speed.

6. The standard diaphragm does a reasonably good job of preventing moisture intrusion because the holes are often undersized, and a lip often protrudes forward from the face of the diaphragm.

7. The factors which govern moisture intrusion through the holes are not well understood because of the complex flow field which exists at the face of the diaphragm.

B. Recommendations

To minimize moisture intrusion into the TOW missile launch tube, holes in the diaphragm should be as small as possible, without risking diaphragm rupture by differential pressure changes. To determine the minimum hole size will require a knowledge of the diaphragm strength and the maximum rate of pressure change during flight. These calculations were beyond the present scope of work for the project. We recommend that they be made if the current level of moisture intrusion is a problem for the TOW missile.

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